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DIFFERENTIATION IN THE CAPE SPENCER FLOW*

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INTRODUCTION

For years the problem of differentiation in igneous rocks has been the cause for prolonged and intense discussion on the part of geologists from all parts of the world, and at present the matter is still far from settled. The relatively recent theory postulated by Bowen¹ that the great variety of igneous rocks is derived from a parental basaltic magma by a differentiation which is brought about by fractional crystallization and the relative movement of crystals and liquid has gained wide recognition. Fenner² has led an attack against the theory on the grounds that the enrichment in iron of the residual liquid during the fractional crystallization of the pyroxene series will not allow for the derivation of the more acidic rocks from the more basic by Bowen's method of differentiation, termed fractionation, alone. The aim of this paper is to present the facts obtained from a detailed microscopic study of a thick Triassic flow from Nova Scotia in their bearing on the prob-

* A thesis submitted to the Graduate School of the University of Wisconsin in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

¹ N. L. Bowen, *The Evolution of the Igneous Rocks*, Princeton University Press, 1928.

² C. N. Fenner, *The Crystallization of Basalts*, *Am. Jour. Sci.*, vol. 18, 1929, pp. 225-253.

lem of differentiation within the flow and of differentiation in general.

Powers and Lane made a careful study of this same flow some fourteen years ago from which they concluded that gravitative differentiation had been operative during its crystallization.³ Several years later Professor Lane very kindly sent to Madison a representative drill core from hole A which penetrated this flow, and it has been through a detailed study of this core that conclusions on this specific problem are herein drawn.

If fractionation as advanced by Bowen has been active through fractional crystallization and the relative movement of crystals and liquid during the cooling of the flow, then it is only natural to expect a more or less progressive change in the composition and properties of the constituent minerals throughout the flow, providing these minerals form a continuous reaction series. In other words, such fractionation should be reflected by a definite trend in the course of crystallization of the plagioclase feldspars and the pyroxenes, the dominant constituent minerals, throughout the flow.

Rosiwal counts of thin sections taken at intervals averaging twenty-five feet were made to determine variations in the mineralogical composition in the flow, and in the main these results substantiated those obtained by Powers and Lane. A noticeable enrichment of pyroxene was found just below the middle and an even more striking enrichment of feldspar was found above the middle part of the flow.

A determination of the refractive indices of the pyroxenes at eight different points in the flow was made by the use of the double variation method as described by Emmons.⁴ The results, while seeming to portray in the main a progressive trend in the composition and properties of the pyroxenes, were sometimes erratic, probably due to the presence of pigeonite, within a single crystal of which the optical properties may vary quite considerably. The indices tend to decrease from the margin toward the center of the flow, except for the chilled border, suggesting a decrease in the tenor of iron in the pyroxenes toward the center.

³ S. Powers and A. C. Lane, *Magmatic Differentiation in Effusive Rocks*, *Trans. A. I. M. E.*, vol. 54, pp. 442-457, 1916.

⁴ R. C. Emmons, *American Mineralogist*, vol. 13, 1928, p. 540; *idem*, vol. 14, 1929, pp. 414-426, and pp. 441-461.

The plagioclase feldspars were determined at nine different points within the flow by means of the measurement of extinction angles in sections normal to a bisectrix. These determinations showed in general a trend from more calcic plagioclase at the margins to more sodic plagioclase near the middle of the flow.

Five chemical analyses within the flow given by Powers and Lane⁵ were studied as regards both the variations in the FeO:MgO ratio and the variations in the ratio of the total iron calculated to FeO:MgO. The former of these showed a progressive decrease from each of the margins to a point well above the center of the flow, while the latter followed essentially a similar course in the bottom half of the flow, but departed most radically from it in the upper portion.

When all these results are correlated a marked trend seems to be apparent in the properties and composition of the plagioclase feldspars and the pyroxene series through the flow, together with a progressive change in the FeO:MgO ratio, which strongly suggests, if it does not actually prove, that fractionation brought about by fractional crystallization together with the relative movement of crystals and liquid has been operative during the cooling of the Cape Spencer flow, and that a progressive enrichment in iron of the residual liquid does not necessarily follow in the fractionation of such a mass of basaltic magma.

The kindness of Professor Lane in sending a large set of core samples to Madison, thus making possible this investigation, is hereby acknowledged. Thanks are also extended to Professors Winchell and Emmons of the Department of Geology of the University of Wisconsin for their invaluable help and criticism during the course of the study, and to the University of Wisconsin for granting to the author a fellowship during the year that the investigation was in progress.

REVIEW OF THE LITERATURE PERTAINING TO THE PROBLEM

The Cape Spencer flow is the thickest and lowest of a series of five Triassic lava flows found on Cape d'Or, Nova Scotia, a conspicuous headland extending into Minas Channel from the north. The literature which has been written on the geology of this general region is quite extensive. Powers⁶ has given an excellent pic-

⁵ *Op. cit.*, pp. 452-453.

⁶ S. Powers, The Acadian Triassic, *Jour. Geol.*, vol. 24, 1916, pp. 1-26, 105-122, and 254-268.

ture of the geology of the Acadian Triassic which has been used almost exclusively to obtain a general idea of conditions there. The Bay of Fundy is fringed on the south, and locally on the north, by a series of sedimentary rocks and lava flows showing a gentle monoclinical structure with a prevailing northwesterly dip, interrupted by broad, low folds, and cut by many normal faults which are usually of small displacement. From paleontological and paleobotanical evidences these Acadian rocks have been proved to correspond in age with the Newark group of eastern United States, which in turn has been correlated with the middle and upper divisions of the Alpine Trias. The Acadian Triassic is divided into three formations, being, from oldest to youngest, the Annapolis formation, comprising about 2,000 feet of red beds, largely calcareous, with some small interbedded basaltic flows near the top; the North Mountain basalt, a succession of lava flows totalling from 800-1,000 feet in thickness; and the Scots Bay formation, a calcareous white sandstone which has been stripped by erosion from all localities except the Wolfville-Scots Bay region, where the maximum amount preserved in small synclines is only 12 feet.

The North Mountain basalt, of which the Cape Spencer flow comprises the basal member at Cape d'Or, is quite extensively exposed along the south shore of the Bay of Fundy and in only a few scattered localities on the north shore. It stands out in conspicuous relief due to its marked resistance to erosion as compared with the associated sedimentary beds above and below. In each locality where the basalt is found there are several flows, indicating successive extrusions within such a short time of each other that no sedimentary material was deposited between them. These individual flows are clearly recognized by a thin amygdaloidal base and a relatively thick amygdaloidal top, the amygdules being filled with either quartz, calcite, or a zeolite. The basalt itself is a dark-gray or dark-greenish fine-grained rock composed of plagioclase feldspar and pyroxene with accessory amounts of magnetite, olivine, and glass. The feldspar ranges from sodic bytownite to calcic andesine. The texture of the rock is typically ophitic, so it should more properly be termed a diabase. Chlorite, magnetite, limonite, hematite, and serpentine are present as alteration products.

The work of Powers and Lane,⁷ already mentioned, consisted of a detailed study of a series of six drill cores which penetrated

the North Mountain basalt to a greater or lesser degree at Cape d'Or. Five separate flows were noted, varying in thickness from 11 to 556 feet, the lowest one of which was termed the Cape Spencer flow. It was completely penetrated only by drill hole A, where it was found to be 556 feet thick, with the upper 20 feet being amygdaloidal. A series of volumetric and chemical analyses, and determinations of specific gravity and size of grain were made on core A through the Cape Spencer flow. The results showed a concentration of the leucocratic, felsic constituents at the top of the flow, and the melanocratic, mafic constituents at the base. The quickly chilled top and bottom of the flow, when free from alteration, showed the original composition of the magma. The size of grain of the rock, while difficult to determine with a great degree of accuracy due to several factors indicated, was shown to vary with the depth, being greatest just below the center. The specific gravity determinations showed a marked increase just below the center of the flow with a gradual decrease above and a more sudden decrease below this point. It must be remembered, however, that alteration was not taken into account, so that the determinations should not be interpreted as trends in the specific gravity of the fresh rock. At the top zeolitization and other forms of alteration gave a lighter rock, while at the bottom chloritization and other forms of alteration gave lower figures.

A comparison of the specific gravity determinations with the results for volume composition and size of grain showed a marked agreement between the maximum concentration of the augite, the maximum size of grain, and the maximum specific gravity—all slightly below the center of the flow.

The combined chemical results showed an increase downward in the percentage of ferrous iron, magnesia, lime, and perhaps potash, a decrease in soda, with silica remaining about constant.

They concluded, then, that the results of their investigation of the differentiation within the flow agreed with the experimental results of Bowen and Anderson on artificial solutions; namely, that heavier minerals tend to sink during the cooling while very light minerals may rise.

Bowen's⁸ theory of fractionation to account for the evolution of the various types of igneous rocks from a parental basaltic

⁷ *Op. cit.*

⁸ *Op. cit.*

magma should be explained in more detail. From a very careful, intensive laboratory study of crystallization in silicate systems it was found that a relation of liquid to crystals, characterized by reaction between them, is very common during the normal course of crystallization. The striking difference between crystallization in which reaction is involved and crystallization in purely eutectic systems is plainly indicated, the fundamental difference being that in eutectic systems crystals bear a simple subtraction relation to the liquid, and once subtracted they play no further part in the equilibrium. In the systems exhibiting reaction between crystals and liquid there is a continual reaction between liquid and crystals until the last liquid is exhausted. Any solid solution series exhibits this reaction principle in that there is a continuous reaction between the crystals already formed and the liquid, the change in composition of the crystals being a perfectly continuous one taking place by infinitesimal increments. Such a solid solution series is therefore termed a continuous reaction series.

In a binary system in which a compound is formed which has an incongruent melting point, crystals of the first compound react with the liquid to produce the second during the normal course of crystallization. Such a pair of compounds is termed a reaction pair.

A reaction relation of this latter type may exist between three or more compounds, and the compounds, when arranged in proper order, then constitute a discontinuous reaction series. The distinction between the two types of reaction series lies in the fact that every gradation of composition is exhibited in the continuous series, whereas the change of composition in discontinuous series is by definite steps. Bowen points out that the plagioclase feldspars constitute a continuous reaction series and that pyroxene, amphibole, and mica form a discontinuous series.

The continuous reaction series of the plagioclase feldspars is probably the best understood series of rock minerals, and inasmuch as the series is of such particular importance in igneous rocks, it is fortunate that the series is so well known. In the crystallization of this series there is a continual enrichment of the liquid in alkaline feldspar, with the separation of the potash variety of alkaline feldspar as a separate phase when it has exceeded its solubility in the plagioclase mixture. Bowen further shows how, through the action of the reaction principle, the ferromagnesian minerals pass

from the olivines through the pyroxenes, amphiboles, and biotites, and converge with the continuous reaction series of plagioclases when potash feldspar begins to separate. Liquid which has not been used up in the reaction thus far may then crystallize to form principally potash feldspar and quartz.

The other fundamental requisite to Bowen's theory of fractionation is the relative movement of crystals and liquid. This effectively shuts off the earlier formed crystals from the liquid and prevents them from reacting with it. Thus, since the earlier formed minerals in the plagioclase series, for instance, are more calcic than the liquid from which they crystallize, the course of crystallization will proceed to a point much more alkalic if these earlier crystals are removed and not allowed to react with the liquid. This relative movement of crystals and liquid may be brought about by gravity or by deformative forces, the former being stressed during the comparatively early stages of crystallization while the latter reaches its height of effectiveness only in the middle and late stages of crystallization.

Zoning of minerals, whereby inner zones are effectively prevented from reaction with the liquid, is also of importance in producing fractionation.

VARIATION IN PERCENTAGE MINERAL CONTENT

A series of twenty-seven Rosiwal counts was made from thin sections at intervals averaging twenty-five feet through the flow to determine the variation in percentage mineral content. The fresh rock is composed almost entirely of feldspar, pyroxene, magnetite, and glass; so these were the only constituents considered in the Rosiwal counts. The magnetite and glass were grouped together, inasmuch as the glass is usually intimately associated with very fine-grained magnetite. The medium power objective was used exclusively with the 7.5 micrometer ocular. The thin sections were crossed an average of 9.6 times each, the average linear distance for each section covered in the counts being 7,561 small divisions of the ocular or 120.976 mm. The lines were run parallel to each other for convenience. The sections of a very fine-grained rock, of course, were crossed a lesser number of times than the sections of a coarser grained rock. A check was run on section A-18 from the 161 foot depth at right angles to the first measurement to determine the variation in percentage mineral content intro-

duced either by the personal element or by difference in direction of the lines through the section. The results of this check are given below, and show that agreement was obtained to within roughly two to three percent for each of the constituents.

CONSTITUENT	FIRST DETER- MINATION	SECOND DETER- MINATION	DIFFER- ENCE
Pyroxene	47.1	45.1	2.0
Feldspar	38.2	41.8	3.6
Magnetite and Glass	14.7	13.1	1.6

Linear distance covered in mm. 103.76 112.048

The results are shown in tabular form in Table I and graphically on Plate I. They show a marked agreement with those obtained

TABLE 1.

Section No.	Total Depth	Depth below top of flow	% Feldspar	% Pyroxene	% Magnetite and Glass
A-13	250	36	43.4	32.6	24.0
A-14	275	61	36.1	36.8	27.1
A-15	300	86	33.65	36.7	29.65
A-15a	300	86	37.6	39.6	22.8
A-16	325	111	38.8	43.4	17.8
A-17	350	136	55.1	31.9	13.0
A-18	375	161	40.05	46.05	13.9
A-18a	375	161	50.3	42.8	6.9
A-18b	375	161	51.8	44.9	3.3
A-18c	375	161	52.0	44.0	4.0
A-19a	402	188	53.8	40.5	5.7
A-19	412	198	59.3	32.4	8.3
A-20	462	248	50.3	47.4	2.3
A-21	475	261	45.9	51.8	2.3
A-22	500	286	48.4	47.4	4.2
A-22a	502	288	52.2	43.1	4.7
A-24	505	291	54.0	42.6	3.4
A-23	528	314	47.1	48.0	4.9
A-24a	550	336	49.5	48.0	2.5
A-25	575	361	44.4	49.5	6.1
A-26	600	386	44.0	51.4	4.6
A-27	625	411	51.0	47.6	1.4
A-28	650	436	43.7	46.8	9.5
A-29	675	461	47.4	48.6	4.0
A-30	700	486	52.0	45.0	3.0
A-31	725	511	47.5	44.1	8.4
A-32	750	536	50.9	42.9	6.2

VARIATION IN PERCENTAGE MINERAL CONTENT

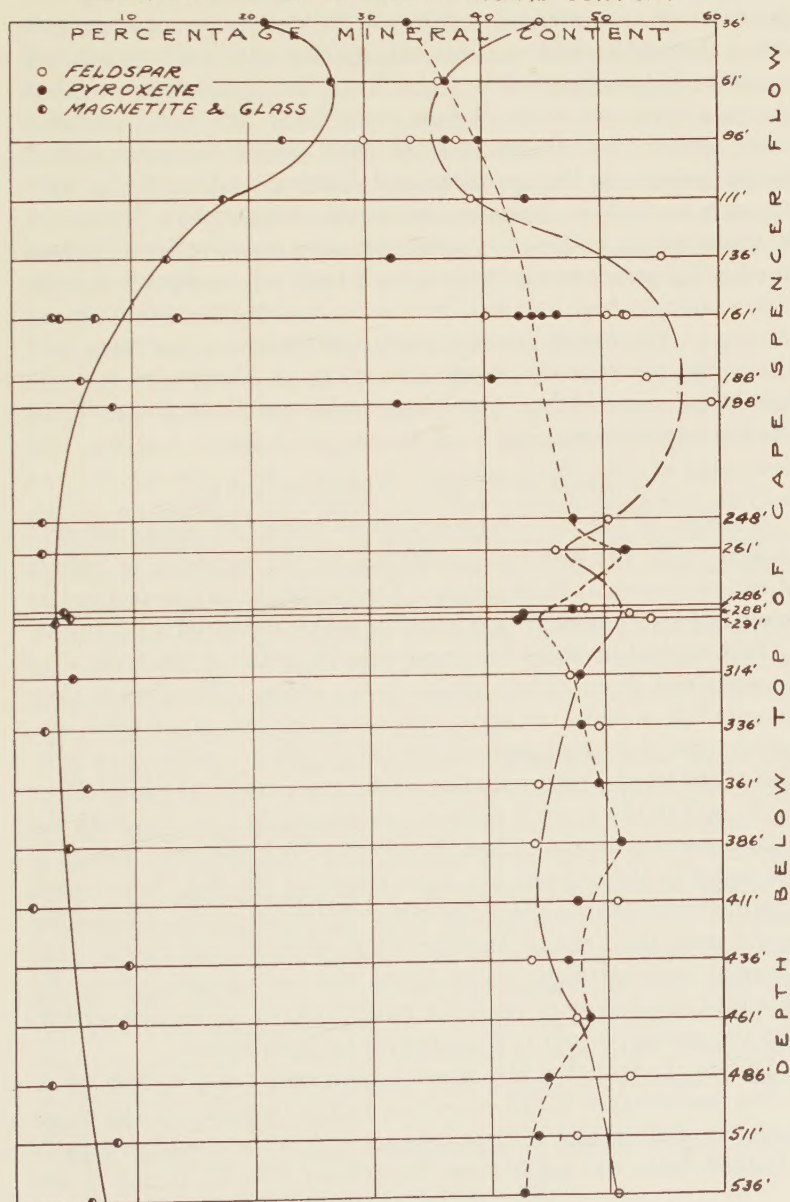


PLATE I

by Powers and Lane⁹ except for a minor variation in the middle of the flow. A very marked enrichment in feldspar is apparent just above the middle with a somewhat less apparent concentration of pyroxene below the middle of the flow. The magnetite and glass rise in a very noticeable amount toward the top, and in a much lesser amount near the base of the flow. The two sudden breaks in the curves for the pyroxene and feldspar at the middle were thought at first to represent relatively insignificant departures from the normal curves; but when the same irregularities appeared in other independent determinations, which will be discussed later, it was thought best to break the curves at this point to bring out this fact. The break shows a slight enrichment of pyroxene just above the center and a more noticeable enrichment of feldspar just below the middle. The interpretation of these facts will be left for a later page.

VARIAION IN THE PYROXENE SERIES

A series of thirteen determinations taken at eight different points within the flow was made to note the variation in indices of the pyroxenes at these points. The double variation method as described by Emmons¹⁰ was used to make these determinations.

This method involves the immersion of grains of the mineral to be examined in an oil of suitable index range. The slide is then mounted on a perfected water cell which fits into a modified universal stage, a suitable grain chosen which will not move upon rotation of the stage, and orientation of the grain made by which either X, Y, or Z in the grain is made to correspond in direction with the axis of the microscope. Then, by varying both the temperature of the water in the cell and the wave length of the light being used, points at which the index of the mineral is equal to the index of the liquid are determined by the Becke line method. The index of the liquid at each particular temperature and wave length is then determined by means of an Abbé refractometer, corrections made, and the points platted to form curves for each index.

Due to the fact that the refractometer only reads indices up to 1.70 a modification of this procedure had to be made for the measurement of the higher indices encountered in the work. A greatly enlarged chart was made from the critical data for liquids 1 and

⁹ *Op. cit.*, p. 447.

¹⁰ *Op. cit.*

2 as given by Emmons,¹¹ and by means of interpolation, curves were drawn at intervals of 5° temperature, while the horizontal interval of 100 millimicrons was divided into tenth lines to facilitate accurate reading of wave length. Checks between readings from the chart and from the corrected refractometer, whenever available, agreed within 0.001 of each other.

Difficulty in getting a long continuous set of points for indices N_o and N_p was nearly always encountered due to the fact that the cold extreme practically never allowed a reading far toward the red for N_o , while the hot extreme very seldom allowed readings far toward the blue for N_p .

In practically all cases no optic angle was observable. In about fifty per cent of the cases this was due to the fact that when the grain was oriented the optic plane was in a horizontal position, and rotations of ninety degrees of the stage are very seldom possible. In the rest of the cases the inability to obtain the angle was due to an inability to rotate quite far enough from the vertical (usually obtuse) bisectrix to locate an axis. The optic angles, therefore, were computed from the indices by means of an enlargement of Wright's graph given by Emmons.¹²

Rotation readings to obtain the index for the direction which was vertical when the grain was oriented, together with calculations of the indices from the observed readings, were made by following the procedure as indicated by Emmons.¹³

In locating exact "change points"—those points at which the index of the mineral is equal to the index of the liquid—by means of the Becke line method it was found necessary to confine the attention to one specific area or edge of the grain in all the readings. This was necessitated by the observation in some grains of good Becke lines moving out upon raising the objective in one part of the grain while good lines moved in in other parts of the same grain. Because of this fact rotation readings may not have attained the accuracy expected, for in rotating the grain it was absolutely necessary to work on a different part or edge of the grain, be it ever so slight a difference. The indices were found to vary, then, within a single grain.

As a result of a cursory examination of the pyroxene in thin

¹¹ R. C. Emmons, *Am. Mineral.* vol. **14**, 1929, p. 417.

¹² R. C. Emmons, *Am. Mineral.* vol. **14**, 1929, p. 459.

¹³ *Ibid.*, pp. 454-461.

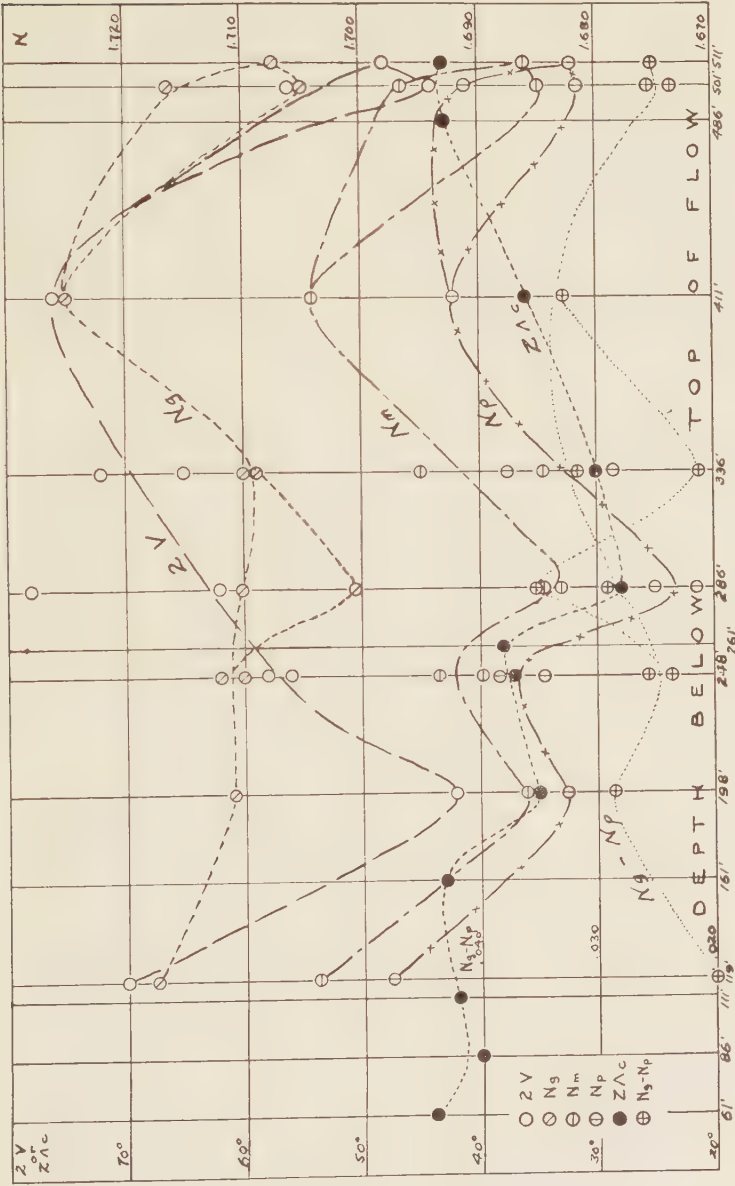
sections on the universal stage it was found that the optic angle (2V) within a single crystal varied as much as from (+)29° up through 90° to (-)83°, or a total of 68°. There was no zoning or any other indication apparent to explain such a fact. The crystal went to good normal extinction, but when the vertical plane was searched for an optic axis it went to extinction in different parts, with no apparent pattern whatsoever, through this wide angular range. Several readings of 0° for 2V were observed which is a characteristic of pigeonite, a member of the pyroxene series. Also, it is known that the optic angle is conspicuously variable in pigeonite,¹⁴ not only in different crystals, but even within a single crystal. Daly and Barth¹⁵ in a recent article have substantiated this fact. Due to the observed facts, then, that the indices may vary within a single grain (through how large a range, unfortunately, is not known) and that the optic angle may vary as much as 68° within a single crystal, and inasmuch as this particular type of pyroxene (pigeonite) is not conspicuously identifiable optically by any other method than by its optic angle and indices, it is at once obvious that the results obtained in this particular phase of the thesis should be accepted only with reservations. It is unfortunate that at this time it is impossible to state the extent of such reservations.

A series of determinations of the extinction angles for the pyroxenes was made at twelve different points within the flow by means of locating crystals in thin section cut normal to *Y*, and measuring the angle between *Z* and *c*.

All these results pertaining to the pyroxenes are shown graphically on Plate II. The graph shows a tendency for the indices to take a rather sudden rise in going upward from the base, then to fall off more gradually toward the center, and to rise, in turn, toward the upper margin of the flow. An abrupt break is apparent between the 248 foot and 286 foot depths. The optic angle follows, in general, the same course, without showing the break to which reference was just made. The extinction angles again show the same trend, without the rise in going upward from the base. The birefringence ($N_o - N_p$) portrays a tendency to rise from the two margins inward.

¹⁴ N. H. and A. N. Winchell, *Elements of Optical Mineralogy*, Part II, 1927, p. 181.

¹⁵ R. A. Daly and T. F. W. Barth, Dolerites Associated with the Karroo System, S. Africa, *Geol. Magaz.*, March, 1930, p. 103.



VARIATION IN PYROXENE SERIES THROUGH FLOW

PLATE II

Plates VI and VII (following bibliography) show two of the double variation graphs obtained in the study. It was from these and ten other similar graphs that most of the data on Plate II were obtained. Plate VI was taken as typifying the pyroxene curves, in which the dispersion for N_m is $F-C=0.0163$. Plate VII shows a striking example of optic axis dispersion due to the rather radical departure of the dispersion for N_m from that for N_o and N_p .

Unfortunately it is impossible to trace this course of properties into terms of chemical composition and thence into a course of crystallization on any graphs found which deal with the pyroxene series. Probably this is due to the entrance of molecules into the mineral which are not shown on the graphs examined.

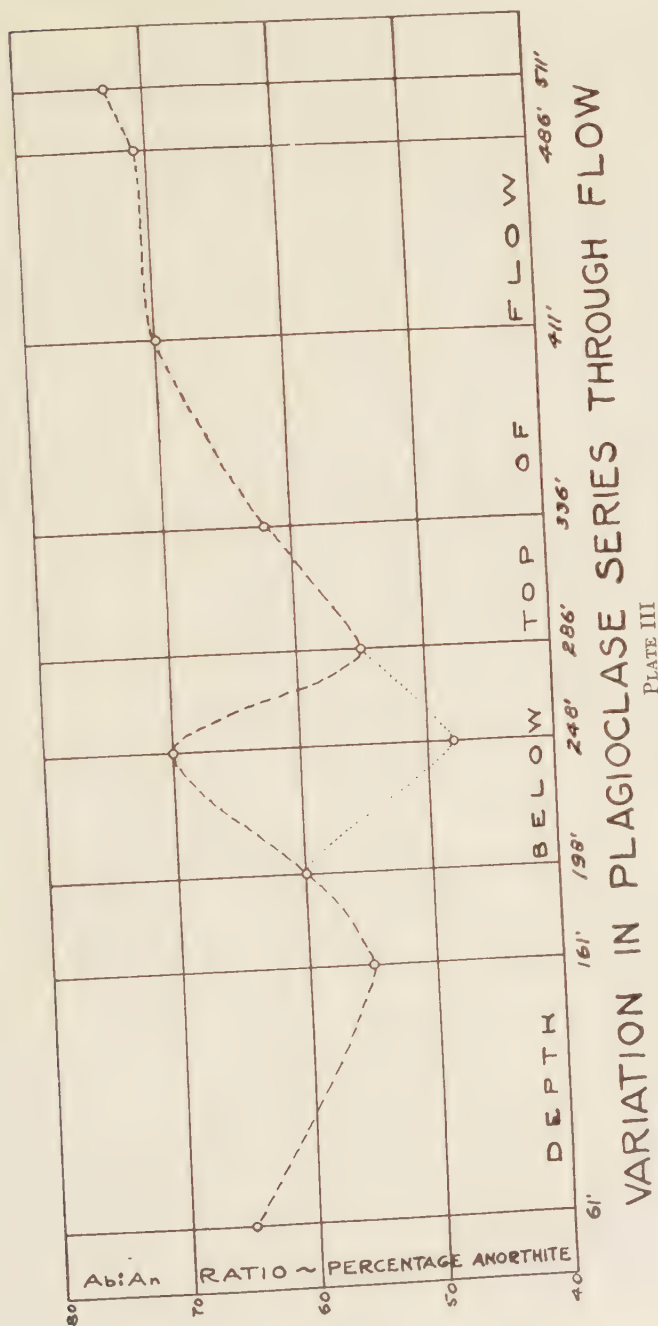
An interpretation of these results will be given in a later section.

VARIATION IN THE PLAGIOCLASE SERIES

Determinations of the feldspars were made at nine different points within the flow by means of the measurement of extinction angles in sections normal to a bisectrix. In one or two cases in which centered bisectrix figures could not be found the feldspar was determined by measuring the maximum extinction angles in the zone perpendicular to (010) between X and (010). The accuracy of the bisectrix determinations is very high, the maximum error probably being within two or three percent for the amount of anorthite present in the mineral.

The results are shown graphically on Plate III. It is shown that in going up from the base of the flow there is a progressive lowering in the amount of the anorthite molecule and hence an increase in the albite molecule until the 286 foot depth is reached. At the 248 foot depth several determinations agreed with the $Ab_{30}An_{70}$ ratio while one grain normal to a bisectrix showed the composition $Ab_{52}An_{48}$. At the 198 foot depth the composition has changed to $Ab_{40}An_{60}$, at the 161 foot depth to $Ab_{45}An_{55}$, while from there up to the 61 foot depth the composition changes until it becomes $Ab_{35}An_{65}$.

If the lower point at the 248 foot depth could be taken instead of the upper, the curve would be quite normal in aspect. As it is, however, the break corresponds in position to that already found for the variation in composition curves and the curves for the variation in the pyroxenes. The range in the feldspar present is not very great, being from sodic bytownite at the 511 foot depth



to calcic andesine for the low point at the 248 foot depth. Practically all of the feldspars, except for these limiting points, fall within the class termed labradorite.

VARIATION IN THE FeO:MgO RATIO

Five chemical analyses given by Powers and Lane¹⁶ were studied as regards both the variation in the FeO:MgO ratio and the variation in the total Fe as FeO:MgO. The chemical analyses, together with the figures for the various ratios studied, are given in Table 2.

TABLE 2.

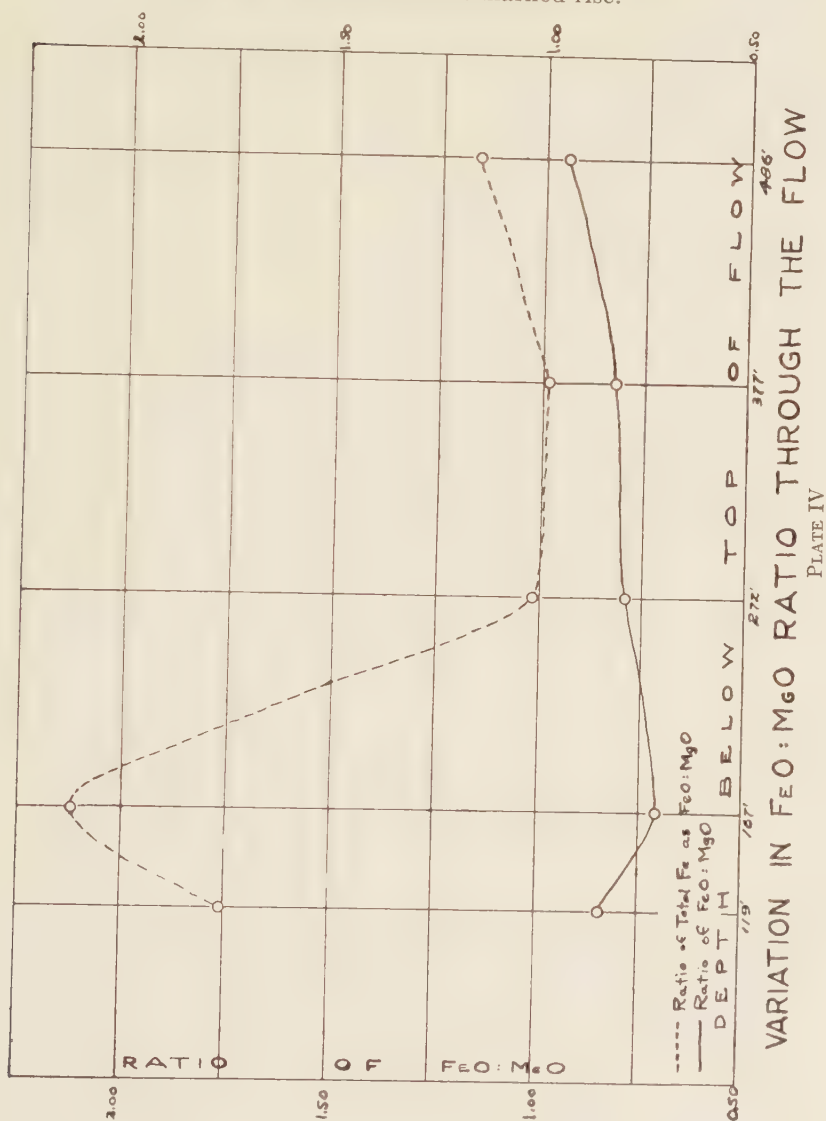
Depth below top of flow	119 ft.	167 ft.	272 ft.	377 ft.	486 ft.
SiO ₂	52.5	53.00	51.92	51.76	51.56
Al ₂ O ₃	14.30	14.71	13.25	13.49	13.57
Fe ₂ O ₃	6.15	7.30	2.28	1.71	2.00
FeO	5.14	3.32	7.16	7.42	7.80
MgO	6.08	4.67	9.05	9.05	8.26
CaO	9.08	9.40	11.22	11.62	10.80
Na ₂ O	2.56	4.11	2.42	2.38	2.58
K ₂ O	0.66	0.71	0.64	0.67	0.69
H ₂ O	1.64	1.00	0.65	0.60	0.90
TiO ₂	1.24	1.30	0.78	0.79	1.14
P ₂ O ₅	0.14	—	—	—	—
CuO	0.002	—	—	—	—
MnO	0.18	0.13	0.14	0.12	0.12
BaO	trace	trace	trace	—	—
Total	99.67	99.65	99.51	99.61	99.42
Ratio FeO:MgO	.846	.711	.791	.820	.944
Ratio of total Fe as FeO: MgO	1.76	2.12	1.02	.990	1.16
Ratio Fe ₂ O ₃ : FeO	1.20	2.20	.318	.230	.256

The analysis from the 119 foot depth was taken from the core of drill hole C, located a little less than $\frac{1}{4}$ mile to the north of drill hole A. All others are from the core of drill hole A.

Plate IV shows the variation in these ratios graphically. The variation in the straight ratio of FeO:MgO shows a progressive

¹⁶ *Op. cit.*, pp. 452-453.

decrease in going upward from the bottom of the flow until the 167 foot depth is reached. From here to the topmost analysis, that at the 119 foot depth, the ratio shows a marked rise.



The variation in the ratio of total Fe as $\text{FeO}:\text{MgO}$ follows practically a parallel course to that just described in the bottom

half of the flow, while in the upper half a most striking increase in the ratio is found, being a maximum of 2.12 at the 167 foot depth. A study of this radical change in character of the analysis for

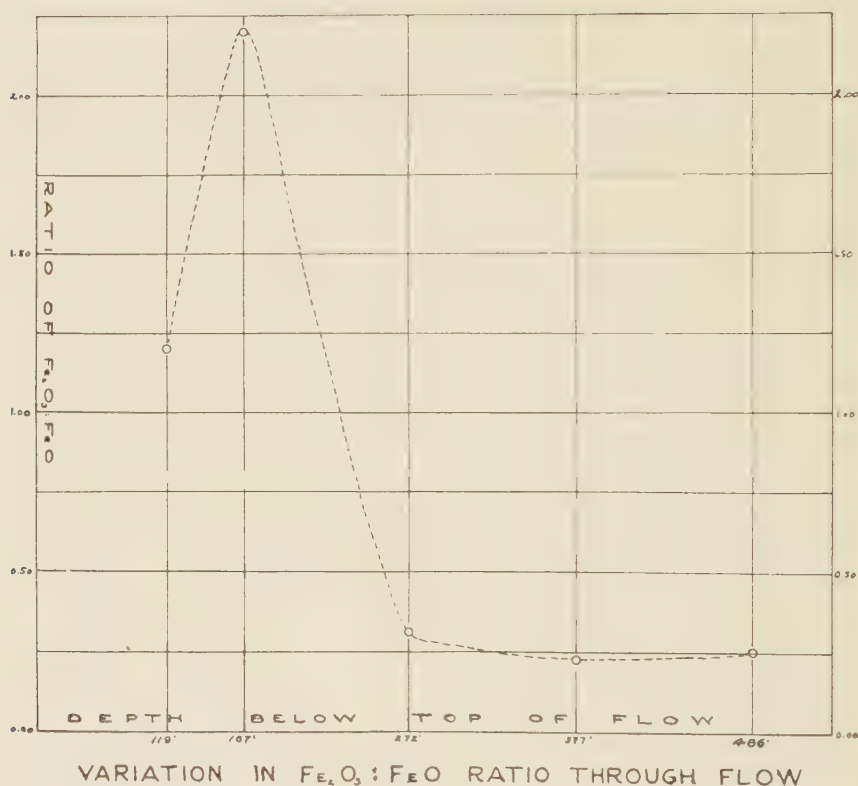


PLATE V

this depth led to an examination of the variation in the $\text{Fe}_2\text{O}_3:\text{FeO}$ ratio. This is shown on Plate V. The rise in the ratio at the 167 foot depth is even more abrupt in this case than in the latter.

An interpretation of these results appears in the next chapter.

INTERPRETATION OF THE RESULTS

A logical interpretation of the facts already presented in the preceding four sections will be attempted in this section. The results of each section will be treated separately, leaving the correla-

tion of all these interpretations for the last division, entitled
CORRELATION OF RESULTS AND CONCLUSIONS

As a result of the numerous Rosiwal counts made through the flow the conclusion is reached that there has been an enrichment of pyroxene in the lower part of the flow—from the 214 foot depth to the 461 foot depth—while there has been an even more striking enrichment of feldspars extending from about the 255 foot depth up to a depth of about 120 feet, with the maximum around the 200 foot depth. Magnetite and glass show a marked enrichment at the top of about 25 per cent, then drop off gradually to around 5 per cent at the 188 foot depth which they hold through the main part of the flow, with a much less marked enrichment near the bottom.

The upper and lower margins show approximately the composition of the magma, the lower being probably more accurate since the percentage of glass of unknown composition is lower. Here there is about 50 percent plagioclase feldspar, 43 percent pyroxene, and 7 percent magnetite plus glass. The results are further interpreted as indicating a gravitative settling of the heavier pyroxene into the bottom part of the flow, thus producing this enrichment; while the feldspar enrichment in the upper part is interpreted as indicating the crystallization of the final liquid of the magma which, through the gravitative settling of the more basic pyroxenes, has thus been enriched in the more alkalic constituents of the magma. The fact that the amount of magnetite and glass is so much higher in the upper part of the flow than in the lower indicates clearly the more rapid chilling which has taken place there.

The breaks in the curves—*i.e.*, the local enrichment of pyroxene at the 261 foot depth and the local enrichment of feldspar at the 288 and 291 foot depths—may be interpreted (1) as irregularities which have been caused either by currents of some nature which have interrupted the normal course of crystallization of the magma or by the engulfment of portions of crust, thus giving an abnormal result to the final crystallization product, and (2) as a definite break in the crystallization of the magma as a whole. According to the latter explanation really two flows would be present rather than only one, with the enrichment in feldspar at the top of the lower one indicated by the high feldspar at the 288 and 291 foot depths, and the enrichment in pyroxene at the base of the upper one represented by the high pyroxene at the 261 foot depth. How-

ever, the small enrichment in feldspar at the 288 and 291 foot depths is far out of proportion to the enrichment in pyroxene below this, while similarly the enrichment in pyroxene at the 261 foot depth is practically negligible as compared to the great enrichment in the feldspar above. A more convincing argument against this latter explanation is that texturally there is no indication of any break here whatsoever—the rock is relatively coarse-grained, no amygdaloid texture is present, and the amount of magnetite and glass is relatively low as compared to that in the rest of the flow. The former explanation is therefore strongly indicated—that the break from the normal curve in the center is merely an irregularity caused by either currents or engulfment of crustal fragments, as already explained.

The results of the study of the plagioclase series as already described indicates a course of crystallization as follows, neglecting the high anorthite figure at the 248 foot depth and the figure for the 198 foot depth. Crystallization of the magma began at the base when plagioclase of a composition slightly more calcic than $\text{Ab}_{27}\text{An}_{73}$ began to separate from a liquid which was more sodic. Crystallization continued upward, with the separation of plagioclase of constantly more sodic character until at the 486 foot depth it was of the composition $\text{Ab}_{29}\text{An}_{71}$. From this depth to the 411 foot depth the change was effected by smaller increments, the composition moving to $\text{Ab}_{30}\text{An}_{70}$. From this depth up to the 361 foot depth crystals of increasingly more sodic plagioclase kept forming from the liquid until they had attained the composition $\text{Ab}_{35}\text{An}_{65}$. At this point crystallization of the plagioclase began at the 61 foot depth also, with crystals of the same composition separating. Crystallization continued to proceed inward within the flow from each edge of the liquid, with constantly more sodic plagioclase separating, the composition of the crystals having changed at the 161 and 286 foot depths to $\text{Ab}_{45}\text{An}_{55}$. This process continued until at the 248 foot depth, or thereabouts, the last of the remaining liquid crystallized to form a rock in which the plagioclase was of the approximate composition $\text{Ab}_{52}\text{An}_{48}$.

Here; again, the break in the normal curve indicated by the plagioclase of the composition $\text{Ab}_{30}\text{An}_{70}$ at the 248 foot depth and by the plagioclase of the composition $\text{Ab}_{40}\text{An}_{60}$ at the 198 foot depth may be interpreted as indicating two separate flows. However, due to the fact that plagioclase of the approximate composition

to be expected at the 248 foot depth was found there, and inasmuch as the factors already outlined strongly suggest the improbability of there being two flows, it is concluded again that these two abnormal determinations indicate merely irregularities which may be expected due to currents of some nature bringing in liquid or crystals foreign to that normal position within the flow or to the engulfment of crustal matter which again will result in a departure from the normal order of crystallization.

The results of the study of the plagioclase series indicate, therefore, that, with these two exceptions, the crystallization in the flow proceeded more or less constantly from the top and bottom with the separation of more and more sodic plagioclase from the residual liquid until the last of the liquid crystallized slightly above the middle to form a rock containing plagioclase of the most alkalic composition. The range, however, is not great, since in the main the plagioclase variations lie within the labradorite group.

The results obtained from a study of the pyroxene series must be accepted, as was stated previously, only with reservations. This is due to the fact that the rotation readings necessary to obtain a complete set of results are of questionable accuracy because of the fact that a different part or edge of the grain had to be used after the rotation, and it was found that the indices and optic angle varied considerably within one grain or crystal. The results should be taken, therefore, as portraying tendencies which probably exist for the majority of the pyroxenes through the flow. These tendencies as already described are for the indices to fall off to lower values from the outermost parts of the flow towards the center; the base, however, showing lower indices also. The abnormality at the 248 foot depth is again apparent.

It is a well established fact that increase in the value of indices in the ferromagnesian minerals is practically proportional to the increase in tenor of iron in these minerals, and vice versa. The results would indicate, therefore, that as crystallization started from the base pyroxenes of higher iron content continued to crystallize until some point in the neighborhood of the 411 foot depth was reached. From here, for some reason or other, the tenor of iron in the pyroxenes began to drop off progressively and crystallization started near the top of the flow soon after this change took place, as already indicated by the feldspars. With continued crystallization of the rock pyroxenes of constantly lower

iron content kept crystallizing until, if the curves were projected below the abnormal readings found at the 248 foot depth, the pyroxenes of minimum iron content would crystallize out at about the depth just named. The extinction angle ($Z.V.c$) follows in general a similar course except for its failure to show a drop near the base of the flow. This general lowering of extinction angle again suggests lower iron content toward the middle of the flow. The birefringence shows a general tendency to rise in value from the margins of the flow toward the middle which, judging from the diopside-hedenbergite system, would again suggest a lower iron content towards the middle of the flow.

The breaks in the pyroxene curves at the 248 and 286 foot depths have already been pointed out. This departure from the normal corresponds in location with those abnormalities already found in the variation in percentage composition and in the variation in the plagioclase series. The results, again, are interpreted as irregularities caused either by currents of some nature or by engulfment of crustal matter.

It is unfortunate that the results could not be traced more specifically into terms of chemical composition and thence into a definite course of crystallization for the pyroxenes. It is suspected that some of the acmite molecule is present to bring up the optic angle so high in the lower-middle and upper parts of the flow, but this is only a surmise. It may be that the pigeonite present has really produced abnormalities in the curves which just above have been interpreted as portraying the properties for the majority of the pyroxenes present in each particular part of the flow studied. The whole matter hinges on the range in indices and optic angle which can be expected in a given grain or crystal of pigeonite, and upon the proportion of pigeonite present in each particular part of the flow studied. Unfortunately time did not permit a comprehensive study of this subject—it would really constitute a problem in itself. The possibility is here suggested that the variability in optical properties of pigeonite may be due to the fact that at ordinary or low temperatures the mineral is not stable and thus breaks up into its chief constituent molecules to form scattered areas of diopside and clinoenstatite. Other molecules—possibly acmite—may have been present in the pigeonite to complicate further the final result. The fact that pigeonite is usually found in effusive rocks which have crystallized rapidly while diopside

and clinoenstatite, its chief constituents, are found in the plutonic rocks strongly suggests such a possibility. An X-ray pattern of the pure pigeonite found in this flow might yield very interesting results.

The results of the study of the variation in the FeO:MgO ratio through the flow indicate a general lowering of the ratio from the base up to the 167 foot depth, where it begins to rise and continues in this course to the 119 foot depth. Since the amount of magnetite is fairly constant through the flow up to the 119 foot depth these results seem to indicate that as the pyroxenes crystallized they did not tend to become enriched in FeO as compared to MgO. The variation in the ratio of total Fe as FeO:MgO follows essentially the same course except for the radical rise in the ratio at the 167 foot depth. The possibility of the analysis having been made from a point in the flow which had been subjected to oxidation and perhaps even to the introduction of FeO was at once suspected. This led to a comparison of the Fe_2O_3 :FeO ratio through the flow, and the even more marked rise in this ratio at this point is strong evidence that oxidation has taken place there. The sudden drop in the value for MgO and CaO suggests further that alteration of a katamorphic nature has been operative on the specimens from which the analyses at the 167 and 119 foot depths have been made. It is concluded, therefore, that inasmuch as indications suggest that these analyses were not made from strictly fresh rock they should not be included in the study of the variations in the FeO:MgO ratio through the flow. The acceptable results indicate, therefore, the crystallization of pyroxene of a lower FeO:MgO ratio from the 486 foot depth up to the 272 foot depth.

CORRELATION OF RESULTS AND CONCLUSIONS

The results obtained from the study of the variations in the mineralogical composition, in the plagioclase series, in the pyroxene series, and in the FeO:MgO ratio have been found to correlate rather nicely. The remarkable agreement in the first three of these phases of the study with regard to the abnormal condition at about the middle part of the flow, constitutes a correlation that cannot be denied. A disagreement introduced by the fact that the variations in the plagioclase series and the pyroxenes indicates the end of crystallization at about the 248 foot depth, while the variation in percentage mineral content indicates from the maxi-

imum feldspar content that crystallization ended at about the 200 foot depth, may be explained by a rising of some of the feldspars as they crystallized. Powers and Lane¹⁷ concluded that the feldspar had risen, so this result substantiates their conclusion.

The fact that agreement was obtained, in general, between the results pertaining to the variation in tenor of iron in the pyroxene series as determined by the measurement of indices and by chemical analyses of the rock constitutes another good check. They both indicate a general decrease in tenor of iron from the margins toward the middle of the flow, except for the chilled borders.

In summary and conclusion, the combined results as obtained through a comprehensive optical study of the Cape Spencer flow indicate that:

(1) A type of differentiation which Bowen has termed "fractionation" was operative during the crystallization of the flow, having been brought about by fractional crystallization of the plagioclase and probably the pyroxene series, together with the relative movement of the pyroxenes and, to a lesser degree, the plagioclase feldspars with respect to the liquid from which the crystals formed.

(2) Crystallization began at the base of the flow when plagioclase of a composition slightly more calcic than $\text{Ab}_{27}\text{An}_{73}$ began to crystallize together with the pyroxene. As crystallization proceeded upward the residual liquid became enriched in alkalic constituents with the consequent crystallization of constantly more sodic plagioclase. The pyroxene formed at the base was higher in MgO than the liquid from which it crystallized, with the consequent enrichment of the liquid in FeO . Pyroxenes of a composition increasingly higher in FeO with respect to MgO continued to crystallize until about the 411 foot depth was reached. From this point onward, for some reason or other, the pyroxenes failed to show this increase in tenor of FeO with respect to MgO , actually indicating a decrease in this ratio. When crystallization had proceeded to the 361 foot depth, when the plagioclase had attained the composition $\text{Ab}_{35}\text{An}_{65}$, crystallization also began at the 61 foot depth, with the separation of plagioclase of the same composition. As crystallization proceeded, plagioclase of increasingly alkalic composition continued to crystallize, together with pyroxene of increasingly low tenor of

¹⁷ *Op. cit.*, p. 447.

FeO with respect to MgO, until at approximately the 248 foot depth the last of the residual liquid crystallized to form plagioclase of the composition $\text{Ab}_{52}\text{An}_{48}$ together with pyroxene of the lowest FeO:MgO ratio.

(3) An abnormal condition in the middle part of the flow is due either to currents of some nature bringing in foreign matter or to the engulfment of foreign crustal matter.

(4) A progressive enrichment in tenor of iron of the residual liquid as postulated by Fenner is not indicated during the crystallization of this flow.

(5) The amount and cause of the range in variation of the optical properties of pigeonite is unknown and constitutes a very interesting problem in mineralogical research.

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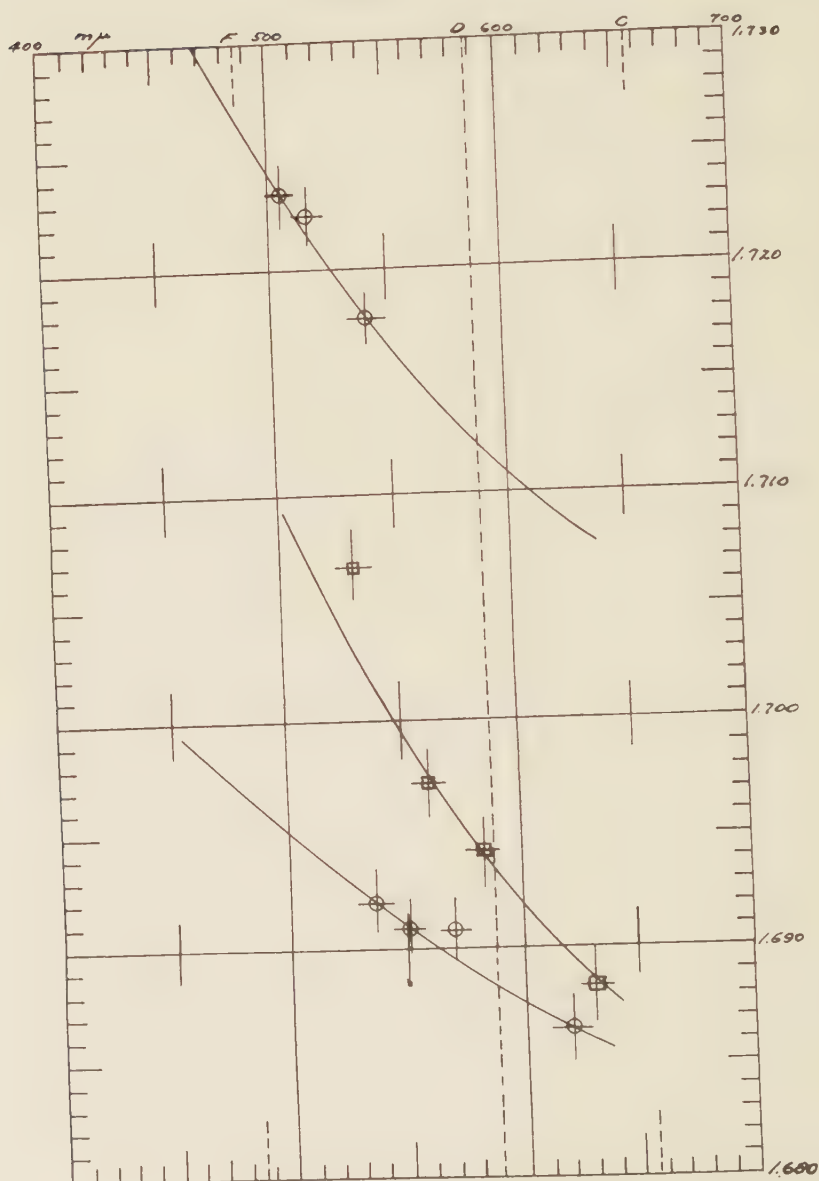
DOUBLE VARIATION GRAPH

Pyroxene ~ 248'

$$\left. \begin{array}{l} N_g = 1.7120 \\ N_m = 1.6935 \\ N_p = 1.6883 \end{array} \right\} \pm 0.0005$$

$$N_g - N_p = .0237$$

$$2V = 45.8^\circ \pm 2^\circ$$



DOUBLE VARIATION GRAPH

Pyroxene ~ 198'

$$\left. \begin{array}{l} N_g = 1.7109 \\ N_m = 1.6860 \\ N_p = 1.6825 \end{array} \right\} \pm .0005$$

$$N_D - N_p = .0284$$

$$2V = 42^\circ \pm 2^\circ$$

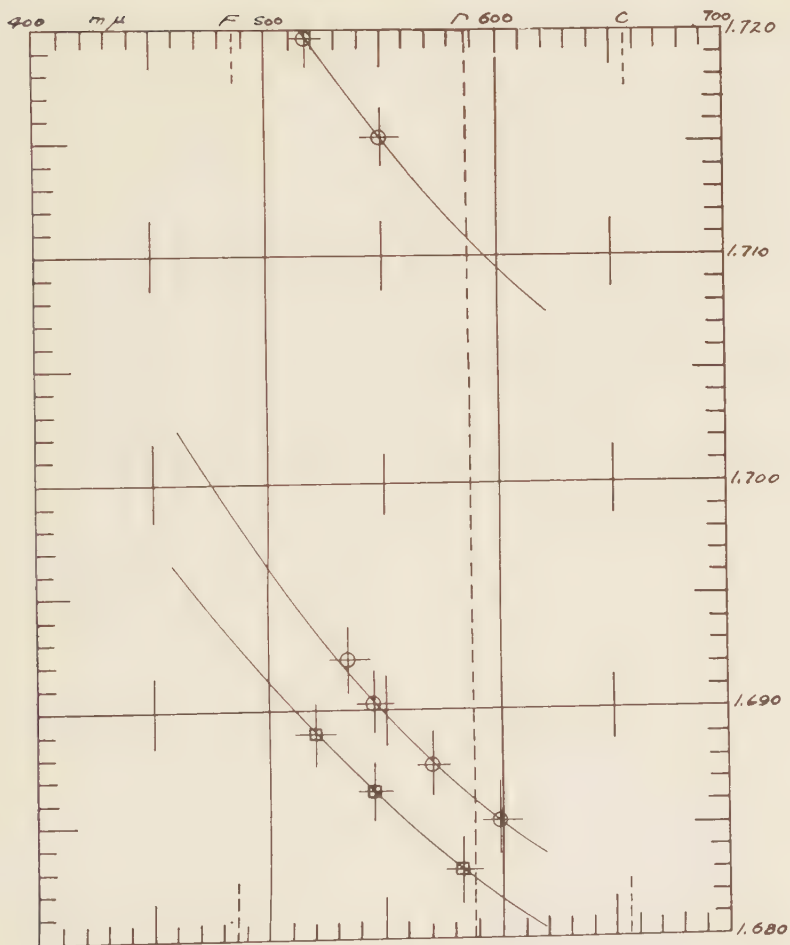


PLATE VII

ADJECTIVAL ENDING OF CHEMICAL ELEMENTS USED AS MODIFIERS TO MINERAL NAMES*

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This paper is concerned with the question, can a uniform, clearly understandable scheme of nomenclature be adopted to express a minor and variable isomorphous replacement of an essential chemical element of a mineral by another analogous element?

Take, for example, celestite, strontium sulphate. Suppose we are describing a variety containing several per cent of barium isomorphously replacing a minor part of the strontium. How should such a variety be designated? By present usage any one of several expressions could be used—baric celestite, baricelestite, bariferous celestite, baro-celestite, barium celestite, barium-bearing celestite. Most of such expressions can be interpreted by the reader in more than one way. They may be taken to mean either a minor replacement of strontium by barium or a major, almost complete, replacement, yielding a compound that is essentially barium sulphate.

To cite another example, what does an author mean when he refers to a sodium orthoclase, a soda orthoclase, a sodic orthoclase, a sodiferous or a soda-bearing orthoclase? Does he mean a partial or complete replacement of potash, a chemical or a mineralogic isomorphism, a mechanical mixture of two mineral species (such as an intergrowth), or something still different?

Taking Dana's *System of Mineralogy*, 6th edition, as a comprehensive example of mineralogic literature, we find various methods used to indicate such minor and variable isomorphous replacement. Thus Dana lists the following terms:

1. Using the suffix *iferous*:
 - Seleniferous sulphur (p. 10).
 - Argentiferous gold (p. 15).
 - Ferriferous sphalerite (p. 61).
 - Zinciferous rhodochrosite (p. 278).
 - Cupriferous smithsonite (p. 279).
 - Chromiferous pyromorphite (p. 770).
2. Using the suffix *ian*:
 - Magnesian magnetite (p. 225).
 - Manganesian titanite (p. 714).

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3. Using the suffix *al*:

Antimonial arsenic (p. 12).

Arsenical silver (p. 43).

Mercurial sphalerite (p. 61).

A similar form is also used as a synonym for a mineral as antimonial silver for dyscrasite.

4. Using the suffix *eous*:

Cupreous manganese (lampadite, var. psilomelane, p. 258).

5. Using the suffix *ic*:

Bismuthic gold (probably not isomorphous, p. 15).

6. Running the adjective and mineral name together:

Manganbrucite (p. 252).

Baricalcite (p. 269).

Ferrocalcite (p. 269).

Zincocalcite (p. 269).

Plumbocalcite (p. 269).

Manganpectolite (p. 374).

Manganapatite (p. 766).

Cuprodescloizite (p. 788).

Celestobarite (p. 902).

Calciocelstite (p. 906).

Similar compound names are used for mineral species, whose chemical composition is accurately expressed by the name, as manganotantalite, ferri-tungstite, natrojarosite.

Similar forms that do not express such a relationship are also used as names of mineral species, as arsenopyrite (should have been named arsenomarcasite, being orthorhombic like marcasite and not isometric like pyrite), which is not a pyrite containing some arsenic; ferronatrite, which is not a natrite (synonym of natron) containing some iron; bismutosphaerite, which is not a sphaerite containing bismuth.

7. Using a hyphen:

Palladium-gold (p. 15).

Ferro-goslarite (p. 939).

8. Adding the chemical name:

Chromium mica (fuchsite, var. of muscovite, p. 617).

Barium mica (oellacherite, var. of muscovite, p. 617).

The name of the replacing element (for some the Latin form) with the proper suffix added seems the most desirable of the several forms listed. The use of a suffix is indicated above in 1, 2, 3, 4, and 5. There is thus formed a two-word phrase, short, accurate, and, if used consistently, readily conveying its meaning. Before considering the question whether or not a single suffix can be applied for all elements, the remaining usages (6, 7, and 8) may be briefly considered critically.

Joining the adjective and mineral name together (6) is too

uncertain as to the meaning. The first example cited above, "manganbrucite," does not differentiate between (a) a brucite in which a minor and variable quantity of manganese replaces a small portion of the magnesium, and (b) a mineral analogous to brucite ($\text{MgO} \cdot \text{H}_2\text{O}$) with the formula $\text{MnO} \cdot \text{H}_2\text{O}$ (pyrochroite). The term "manganbrucite" may be interpreted by a reader as synonymous with pyrochroite. The same difficulty arises with the other examples and with any other term so formed. As a matter of fact, the running together of the names of a chemical element and of a mineral species has been used in the naming of individual species of an isomorphous group, as is well shown by the minerals analogous to jarosite—plumbojarosite, argentojarosite, natrojarosite, ammoniojarosite.

The use of the hyphen (7) is very uncommon but is open to the same objection, perhaps even to a greater degree.

Adding the chemical name before the mineral name (8) leads to the same confusion as joining the adjective and mineral name together. Does "chromium mica" mean a mica in which a little chromium replaces a minor part of the aluminum or a mica in which chromium is one of the essential constituents? The term "chromium-bearing mica" would be much better than "chromium mica."

If a single suffix can be found that will apply to the names of all chemical elements and if it is used consistently, then a two-word phrase, in which the first word denotes the replacing element and the second word is the name of the mineral in which isomorphous replacement of a minor and variable extent has occurred, will partake of a definite meaning readily interpretable by all.

After considering the suffixes in use, as listed above, and also others, the writer has concluded that the ending *ian*, or *oan* if it is desired to indicate a lower valency, is the most satisfactory, and its consistent use is here advocated. A chromium muscovite, or a chromium-bearing muscovite, given the variety name fuchsite, would then be called chromian muscovite. Similarly the variety of brucite called manganbrucite would be called manganooan brucite. If the chemical element has only one valency or the author does not wish to bring up the question of valency, *ian* should be used. There is no chemical element whose name ends in *an*, *ian*, or *oan*.

The objections to the use of other suffixes are noted below. The

various suffixes have been tried out on all the names of chemical elements, but most of such endings yield a few unsatisfactory names. The sound of the spoken form must be considered, though the written form would deserve the greatest consideration. Any scheme proposed must be adaptable to the names of all the chemical elements, to allow for any possible mineral combination that may be found in the future.

The main objection to *ic* lies in the possible "confusion which would result, owing to the use of this ending by chemists in a definite technical sense."¹ Chemists use it technically to express high states of oxidation. Thus ferric, manganic, and others are well understood chemical terms, used by way of contrast to ferrous, manganous, etc. The ending *ic* is also so generally used in such terms as geologic, electric, and topographic, that it could not be confined to a definite meaning. It is also the termination of the names of most acids, as carbonic, sulphuric, and phosphoric. The form for cesium would become cesic (seasick!), clearly understood when written but perhaps confusing when spoken. Changing *ic* to *itic* might be clearer, but the terms would be cumbersome and some at least not very euphonious.

A similar objection applies to *ous*, a recognized chemical ending denoting a lower state of oxidation. Thus ferrous, manganous and sulphurous are common chemical terms. Neither *ic* nor *ous* allows any latitude to express different valencies.

The ending *al* is one of the best and has few objections. Some of the words with this ending would not be euphonious.

The ending *iferous* is commonly used in mineralogic literature. It was recommended in Topic 6, D (last page) by the Committee on Nomenclature and Classification of the Mineralogical Society of America for 1923. As clearly defined by Wherry,² "Varieties based on isomorphism are also described by adjectives, constructed by adding the suffix *iferous* to the names of the elements present in the lesser amounts.*** In minerals in which one element is clearly essential and others replace it isomorphously, in widely varying but never significant amounts, the plan adopted in the preceding paper is followed: the name of the replacing element, with the suffix *iferous*, is used as an adjective." Although most

¹ Wherry, E. T. personal communication.

² Wherry, E. T., The nomenclature and classification of sulfide minerals: *Washington Acad. Sci. Jour.*, vol. 10, p. 487, 1920.

commonly used by Dana and other writers, *iferous* is open to two objections. It is long, giving such cumbersome words as *magnesisiferous*, *aluminiferous*, and it may be misleading. Thus, some students would interpret the ending as relating to iron on account of the *ferous*. Wherry³ now feels the weight of these objections and recommends the use of the ending *ian*.

The names of all the chemical elements would be placed in seven groups. In each of the first six groups all the names would have the same ending; the seventh group would include names with various endings. The adjectival ending of the names of all the chemical elements is formed according to the rules given under each group. Ordinary usage is followed in applying the suffix to the names. Latin names are used for copper, (*cuprum*), gold (*aurum*), iron (*ferrum*), lead (*plumbum*), silver (*argentum*), and tin (*stannum*). *Stibium* is optional for antimony, *natrium* for sodium, and *wolfram* for tungsten, but *hydrargyrum* is not used for mercury and *kalium* is not ordinarily used for potassium. If lower valency is to be expressed, use *oan* instead of *ian*, as in *ferroan* and *ferrian*.

GROUP 1. If the name ends in *um*, drop the *um*, and add *ian* (or *oan* if a lower valency is to be expressed).

Aluminum—aluminian.

Ferrum—ferroan and ferrian.

GROUP 2. If the name ends in *ium*, drop the *um*, and add *an*.

Barium—barian.

GROUP 3. If the name ends in *ine*, drop the *ne*, and add *an*.

Bromine—bromian.

GROUP 4. If the name ends in *on*, add *ian*, except for boron and silicon.

Carbon—carbonian.

For boron and silicon, drop the *on* and add *ian*.

Boron—borian.

Silicon—silician.

The abbreviated forms for boron and silicon follow the generally adopted usage, as the shorter forms *boric acid* and *silicic acid* are more commonly used in mineralogic literature than *boracic acid* and *siliconic acid*. For iron, the Latin name *ferrum* is used (Group 1).

GROUP 5. If the name ends in *gen* (three gases), add *ian*.

Hydrogen—hydrogenian.

³ Personal communication.

GROUP 6. If the name ends in *y*, drop the *y*, and add *ian* (or *oan*).

Antimony—antimonian

Mercury—mercuroan and mercurian.

GROUP 7. For the following names, use the form shown.

Arsenic—arsenoan and arsenian.

Bismuth—bismuthian.

Cobalt—cobaltian.

Manganese—manganoan and manganian.

Nickel—nickelian.

Phosphorus—phosphorian.

Sulphur—sulphurian.

Zinc—zincian.

Tungsten—tungstenian or wolframian.

The adjectival endings thus formed for the names of all the chemical elements are given below.

Aluminum—aluminian	Helium—helian
Antimony—antimonian	Holmium—holmian
Argon—argonian	Hydrogen—hydrogenian
Arsenic—arsenoan, arsenian	Indium—indian
Barium—barian	Iodine—iodian
Beryllium—beryllian	Iridium—iridian
Bismuth—bismuthian	Iron—ferroan, ferrian
Boron—borian	Krypton—kryptonian
Bromine—bromian	Lanthanum—lanthanian
Cadmium—cadmian	Lead—plumbian
Calcium—calcian	Lithium—lithian
Carbon—carbonian	Lutecium—lutecian
Cerium—cerian	Magnesium—magnesian
Cesium—cesian	Manganese—manganoan, manganian
Chlorine—chlorian	Mercury—mercuroan, mercurian
Chromium—chromian	Molybdenum—molybdenian
Cobalt—cobaltian	Neodymium—neodymian
Columbiun—columbian	Neon—neonian
Copper—cuproan, cuprian	Nickel—nickelian
Dysprosium—dysprosian	Nitrogen—nitrogenian
Erbium—erbian	Osmium—osmian
Europium—europian	Oxygen—oxygenian
Fluorine—fluorian	Palladium—palladian
Gadolinium—gadolinian	Phosphorus—phosphorian
Gallium—gallian	Platinum—platinian
Germanium—germanian	Potassium—potassian
Gold—aurian	Praseodymium—praseodymian
Hafnium—hafnian	

Radium—radian	Tellurium—tellurian
Radon—radonian	Terbium—terbian
Rhenium—rhenian	Thallium—thallian
Rhodium—rhodian	Thorium—thorian
Rubidium—rubidian	Thulium—thulian
Ruthenium—ruthenian	Tin—stannian
Samarium—samarian	Titanium—titanian
Scandium—scandian	Tungsten—tungstenian
Selenium—selenian	Uranium—uranoan, uranian
Silicon—silician	Vanadium—vanadian
Silver—argentian	Xenon—xenonian
Sodium—sodian	Ytterbium—ytterbian
Strontium—strontian	Yttrium—yttrian
Sulphur—sulphurian	Zinc—zincian
Tantalum—tantalian	Zirconium—zirconian

Where an element shows more than two valencies, the proper form can easily be made. Thus, for vanadium.

For vanadous vanadium, valency of 3, use vanadoan.

For vanadyl vanadium, valency of 4, use vanadylian.

For vanadic vanadium, valency of 5, use vanadian.

Some practical examples would then be:

Aluminian chromite for a chromite with a minor quantity of aluminum replacing part of the chromium.

Antimonian tennantite if the mineral contains a little antimony.

Barian celestite

Cadmian sphalerite

Calcian siderite

Cerian xenotime

Ferrian variscite

Manganoan siderite (manganous manganese)

Manganian spodumene (manganic manganese)

Rubidian lepidolite

Uranoan zircon (uranous uranium)

Uranian fergusonite (uranic uranium)

Tungstenian or wolframian powellite

Zincian tetrahedrite

The various forms given by Dana and listed in the earlier part of this paper, except for those of group 2 which remain unchanged, would then be changed as follows:

Seleniferous sulphur becomes selenian sulphur

Argentiferous gold becomes argentian gold

Ferriferous sphalerite becomes ferroan sphalerite

Zinciferous rhodochrosite becomes zincian rhodochrosite

Cupriferous smithsonite becomes cuprian smithsonite
 Chromiferous pyromorphite becomes chromian pyromorphite
 Antimonial arsenic becomes antimonian (or stibian) arsenic
 Arsenical silver becomes arsenian silver
 Mercurial sphalerite becomes mercurian sphalerite
 Cupreous manganese becomes cuprian manganese (psilomelane)
 Bismuthic gold becomes bismuthian gold
 Manganbrucite becomes manganoan brucite
 Baricalcite becomes barian calcite
 Ferrocalcite becomes ferroan calcite
 Zincocalcite becomes zincian calcite
 Plumbocalcite becomes plumbian calcite
 Manganpectolite becomes manganian pectolite
 Manganapatite becomes manganian apatite
 Cuprodescloizite becomes cuprian descloizite
 Celestobarite becomes strontian barite
 Calciocelstite becomes calcian celestite
 Palladium-gold becomes palladian gold
 Ferro-goslarite becomes ferroan goslarite
 Chromium mica becomes chromian mica
 Barium mica becomes barian mica

Some names of varieties of minerals would be abandoned, the two-word phrases being used instead, thus doing away with the uncertainty of determining whether a nondescriptive mineral name represents a species or only a variety of some species whose name bears no relation to the name of the variety. Thus

Marmatite becomes ferroan sphalerite
 Przibramite becomes cadmian sphalerite
 Tarnowitzite becomes plumbian aragonite
 Tawnawite becomes chromian epidote
 Danaite⁴ becomes cobaltian arsenopyrite
 Freibergite becomes argentian tetrahedrite
 Schwatzite becomes mercurian tetrahedrite
 Malinowskite becomes plumbian tetrahedrite
 Sandbergite becomes zincian tennantite
 Worobieffite becomes cesian beryl
 Actinolite becomes ferroan tremolite (as long as the molecular ratio of MgO is greater than that of FeO)
 Cuprogoslarite becomes cuprian goslarite
 Pisanite becomes cuprian melanterite or ferroan boothite, depending on whether iron or copper is in excess (molecularly)
 Nicholsonite becomes zincian aragonite
 Molybdosodalite becomes molybdenian sodalite
 Ferroprehnite becomes ferrian prehnite

⁴ This term is liable to be confused with danalite.

The two-word phrase would then be interpreted as referring to a minor and variable isomorphous replacement of an essential constituent. It would also mean that a *variety* of the mineral is being named.

Obviously, the scheme above set forth would apply only to single isomorphous replacement. If the essential element of the mineral is replaced by more than one element, then the name of the element whose replacing effect is the largest, or is for some reason to be emphasized, would be used. Thus if a brucite contains 5 per cent of MnO (molecular ratio 0.07), 2 per cent of ZnO (molecular ratio 0.02), and 1 per cent of FeO (molecular ratio 0.01), it would still be called manganoan brucite. The determination as to which element has the largest replacing effect should be based on molecular ratios and not on chemical percentages. If more than one essential chemical element in a mineral is partly replaced by other elements, then the element showing the greatest replacement should be chosen for the adjectival name.

For many minerals (such as tourmaline) the question of isomorphous replacement is so complex that the problem of determining what scheme should be used for naming the varieties can well be left to the future. The number of varieties to which the plan herein suggested is applicable is sufficiently large to warrant its consideration. Perhaps the plan, if acceptable, will suffice as a beginning upon which decisions as to the more complex questions can be based.

PSITTACINITE FROM THE HIGGINS MINE, BISBEE, ARIZONA

STEPHEN TABER, *University of South Carolina*, and WALDEMAR
T. SCHALLER, *U. S. Geological Survey*.*

Specimens of a cleavable, olive-green mineral, in manganese ore, from the Higgins Mine, near Bisbee, Arizona, were sent to one of the authors (Taber) by Mr. Carl Trischka of the Phelps Dodge Corp., Copper Queen Branch, in October 1927. Similar specimens obtained from Mr. David H. White, superintendent of the mine, by Dr. D. F. Hewett, when he visited the property in 1928, were submitted to the other author (Schaller). Preliminary examination showed the green mineral to be a vanadate and to be related to and probably identical with what has been termed cuprodesclowitzite but which, as explained later, is more correctly called psittacinite. In the described occurrences of this mineral, it has been reported as occurring either in fine-grained compact masses, as thin crystalline crusts with occasional distinct minute microscopic crystals, or in an earthy pulverulent form. In the Higgins Mine the psittacinite forms aggregates of anhedral crystals, the largest of which have uniform cleavage surfaces extending as much as two centimeters across. Since it has not previously been reported in large crystals, a brief description of the mineral is given.

The general geology of the Bisbee district and the occurrence of the deposits of manganese ore have been described by Jones and Ransome.^{a,1} The ore bodies are irregular replacement masses formed along a zone of fissuring in the Escabrosa limestone. Along the fissure zone there has been some minor faulting followed by considerable silicification and the deposition of the manganese ore. The ore was reported to be chiefly psilomelane but Hewitt² found that the principal mineral "is braunite in the form of myriads of minute octahedrons."

The psittacinite occurs in coarsely granular masses composed of an aggregate of anhedral crystals, ranging up to about two centimeters in diameter, with a well-defined cleavage in one direction and possibly a second poor cleavage in another direction. Well-defined cleavage pieces show parallel extinction and the

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^a Reference given at end of paper.

mineral is probably orthorhombic. The luster is adamantine and the color dark olive-green, in places almost black due to inclosed manganese oxide. The streak of the pure mineral is yellow (Reed yellow, Pl. XXX, 23b, Ridgway's "Color standards and nomenclature"). The psittacinite can be differentiated readily from the closely associated higginsite which is much lighter in color and has a yellowish-green powder.³

The indices of refraction are high, exceeding 2.2, approximate determinations being $\alpha = 2.22$ and $\gamma = 2.33$. Dispersion strong, $\rho > \nu$. In thin sections the mineral appears non-pleochroic, but in thicker fragments it is distinctly pleochroic from yellow to olive-green. The psittacinite is later than the braunite and most of the other minerals with which it is in contact. It is intimately associated with higginsite and large white platy crystals of barite.

ANALYSES OF PSITTACINITE FROM BISBEE, ARIZONA

	Higgins Mine W. T. Schaller, analyst	Shattuck Mine R. C. Wells, analyst
V ₂ O ₅	21.11	21.21
As ₂ O ₅	trace	1.33
P ₂ O ₅	—	0.24
CrO ₃	—	0.50
PbO	50.13 ^a	55.64
CuO	19.10	17.05
ZnO	none	0.31
H ₂ O	4.79 ^b	3.57
Insol.	3.06 ^c	0.17
Total	98.19	100.02

^a The determination is probably low.

^b Ignition loss.

^c Manganese oxide.

The analysis was made on a small quantity of material, the grains of psittacinite being carefully hand picked under a microscope so as to avoid, as far as possible, the small inclusions of the black manganese mineral which are not visible to the unaided eye. The inclusion of about three per cent of the manganese mineral could not be avoided, but it could be readily separated from the vanadate, in the course of the analysis, on account of its insolubility in HNO₃. It is reported as MnO₂. The analysis must be

considered as only approximate and made primarily for the purpose of confirming identification. The high ignition loss should not, necessarily, be interpreted to mean that this mineral contains more water than usual. For comparison there is added the analysis by Wells¹ of the same mineral (called cuprodescloizite) from the Shattuck Mine, which is about 2500 feet southeast of the Higgins Mine. The Shattuck mineral occurs in the form of stalactites, with a radiating structure, and is dark brown in color and strongly pleochroic from yellow to brown.

The ignition loss reported in the analysis represents essentially water but includes some carbon dioxide as a little carbonate (malachite? or calcite?) was present in the sample. A careful test for zinc failed to reveal its presence. No zinc is reported, also in the analysis of higginsite.³

The ratios calculated from the two analyses of psittacinite from Bisbee, Arizona, are as follows:

RATIOS OF ANALYSES OF PSITTACINITE FROM ARIZONA

	Higgins Mine	Shattuck Mine
V ₂ O ₅	.1161 = 1.00	.1266 = 1.07
PbO	.2246 = 1.94	.2493 = 2.10
CuO	.2399 = 2.07	.2180 = 1.84
H ₂ O	.2661 = 2.29	.1983 = 1.67

Except for the high water, the ratios agree with those of the other minerals of this group:

Descloizite	$2\text{ZnO} \cdot 2\text{PbO} \cdot \text{V}_2\text{O}_5 \cdot \text{H}_2\text{O}$
Higginsite	$2\text{CuO} \cdot 2\text{CaO} \cdot \text{As}_2\text{O}_5 \cdot \text{H}_2\text{O}$
Olivenite	$2\text{CuO} \cdot 2\text{CuO} \cdot \text{As}_2\text{O}_5 \cdot \text{H}_2\text{O}$

The ratios of both analyses approximate the formula $2\text{PbO} \cdot 2\text{CuO} \cdot \text{V}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$, which is that ascribed to psittacinite by Dana. It differs in type from that of descloizite only in containing two molecules of water instead of one. It is to be noted that all analyses of the lead-copper vanadate, free or essentially free from zinc, (psittacinite, mottramite) give a water content (about 4 per cent) agreeing with two molecules of water. On the other hand, two analyses^b of cuprodescloizite with dominant copper but still

^b Nos. 17 and 19, as listed by Doelter, C., *Handb. d. Mineralchemie*, vol. 3, p. 839, 1918.

appreciable zinc (11.21 CuO and 4.19 ZnO, and 11.64 CuO and 6.71 ZnO) contain only the quantity of water (2.5 per cent) required for the formula with one molecule of water. No analysis of these minerals is recorded with less than one per cent of ZnO and with a water content agreeing with one molecule of water.

The question is then raised whether a mineral of the formula $2\text{PbO} \cdot 2\text{CuO} \cdot \text{V}_2\text{O}_5 \cdot \text{H}_2\text{O}$, analogous to descloizite, $2\text{PbO} \cdot 2\text{ZnO} \cdot \text{V}_2\text{O}_5 \cdot \text{H}_2\text{O}$, exists, all the analyses indicating a formula with twice the molecular quantity of water, namely, $2\text{PbO} \cdot 2\text{CuO} \cdot \text{V}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$. The analysis by Wells with $1\frac{2}{3}$ molecules of water is closer to the $2\text{H}_2\text{O}$ formula than to the $1\text{H}_2\text{O}$. The analysis of the mineral from the Higgins Mine indicates $2\text{H}_2\text{O}$. The facts now available indicate that the formula for psittacinite, the lead-copper vanadate essentially free from zinc, should be written with $2\text{H}_2\text{O}$, but more evidence is needed before the question can be considered settled.

With regard to the question of nomenclature, psittacinite is considered to be the proper name for this mineral. The name descloizite was given by Damour in 1854 to the lead-zinc vanadate, essentially free from copper. Of the eight analyses of descloizite listed by Dana,⁵ the highest content of CuO in any one analysis is 1.5 per cent. Cuprodescloizite (Rammelsberg 1883) is a variety of descloizite containing copper in considerable quantity. The zinc-free or practically zinc-free lead-copper vanadate, psittacinite, was described by Genth in 1874. The pulverulent material seemed to contain more water than descloizite, Dana writing the formula with $2\text{H}_2\text{O}$. Mottramite (Roscoe 1876) is a similar lead-copper vanadate and as Dana says "may be identical with psittacinite." Two other names are in the literature for the lead-copper vanadate, and have priority over psittacinite, namely chileite (Kennigott 1853) and cuprovanadite (Adam 1869) (see Dana,⁵ p. 792), but neither of these has been used in the last fifty years, (see Limitations of the Law of Priority, Dana⁵, Introduction, p. xliii, rule 13 j) and the name psittacinite is given species rank by Dana (p. 791, No. 567). Psittacinite is the name to be used for the lead-copper vanadate, it having nine years priority over cuprodescloizite. One of the present authors (Schaller) erred in recommending to Wells⁴ the name cuprodescloizite for the stalactitic mineral essentially free from zinc from the Shattuck Mine. It should have been called psittacinite. The term cuprodescloizite should be restricted to the copper-bearing variety of descloizite,

or, still better, the name should be discarded, such varieties being designated as cupriferous descloizite.

It is interesting to note that three minerals of the olivenite group have been found in the Bisbee district; psittacinite and higginsite occurring together at the Higgins Mine, while descloizite has been reported from the Mammoth Mine which is located only about 2 miles southeast.

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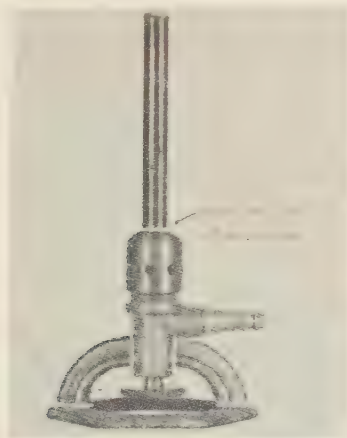
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NOTES AND NEWS

A BROAD SOURCE OF MONOCHROMATIC LIGHT

M. J. BUEGER AND V. F. HARRINGTON, *Massachusetts
Institute of Technology.*

In volume **14** (1929) of this journal, page 329, Buerger and Huntsinger described a source of monochromatic light. The accompanying photographs show a Terrill burner so remodelled, that the height of the flame is considerably less, which makes



it superior for use with the microscope. On the stock burner, the white lines indicate the positions at which it is to be cut; in the brass block, $1" \times \frac{5}{8}" \times \frac{5}{8}"$, (not a part of the stock burner) neither hole must be so drilled as to form pockets which prevent the easy flow of gas around the corner. The mounting of the trough has been changed so that its adjustment can be accomplished with much greater ease. The platinum wire which holds the gauze trough should be flattened before welding to avoid cutting the gauze. The glass tube is fastened in the brass sleeve with sealing wax, or better, with De Kotinski cement. Troughs of nickel gauze are quite as efficient though not as long lived as those of platinum. The largest flame may be had if the air adjustment be fully opened and the gas adjusted to just remove the blue cone.

On the last pages of this Journal will be found a preliminary list of titles of papers to be presented before the Society at its annual meeting to be held at the University of Toronto, Toronto, Canada, December 29–31, 1930.

Professor E. L. Bruce, Miller Memorial Research professor, has returned to Queen's University after spending the summer in Finland.

Mr. William H. Broadwell, a member of the Newark Mineralogical Society, has tested the fluorescent property of the new mineral curtisite, which was described in the May issue of this Journal. He finds that the mineral is quite fluorescent when subjected to ultra violet light, emitting a strong yellow color.

Dr. Cornelio Doelter of Vienna died on August 8 at the age of eighty years. He had been for many years professor at the University of Vienna where he lectured on mineralogy and the chemical composition of minerals.

Adam Hilger, Limited, London, N.W.1, England, has recently issued Bulletin No. 2, on Spectrum Analysis. The index of this 23 page pamphlet shows the following headings: Quantitative Analysis of Metals; Bibliography of Recent Papers on Spectrum Analysis; Official Specifications for Lead, Copper and Zinc; Other Information Concerning Metallurgical Spectrum Analysis; Physiological, Pathological, Toxicological and Pharmaceutical Applications of Spectrum Analysis.

Dr. Edgar T. Wherry of the Bureau of Chemistry and Soils, Department of Agriculture, Washington, D.C., has resigned his position to accept an associate professorship of plant ecology in the department of botany of the University of Pennsylvania.

Copies of a small folder entitled "The 92 Elements" giving their names, atomic numbers, symbols, atomic weights, melting points and years of discovery may be obtained without charge by addressing P. C. Kullman & Co., 110–116 Nassau Street New York City.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, September 4, 1930.

A stated meeting of the Philadelphia Mineralogical Society was held on the above date with the president, Mr. Toothaker, in the chair. Forty-five persons attended the meeting which was devoted to accounts of summer trips.

Messrs. Reinitz, Graham, and Cienkowski reported visits to Rosiclare, Illinois; Hot Springs, Arkansas; the Carlsbad Caverns; Bisbee, Arizona; and localities in southern California, and Colorado. Mr. Trudell described a visit to several museums on the Pacific coast. Mr. Gordon described a short sojourn in Canada between Montreal and Toronto.

Mr. Arndt visited New Hampshire and collected a beryl crystal measuring 18 inches in length, and 6 inches in diameter. Mr. Frankenfield collected some stalactites in the Bermuda caves. Mr. Toothaker referred to a trip to North Carolina with Messrs. Biernbaum, Clay, and Gordon. Other trips were reported upon by Messrs. Knabe, McNelly and Warford to Pennsylvania localities, and by Mr. Vanartsdalen to several Virginia quarries.

WILEY H. FLACK, *Sec. pro tem*

Academy of Natural Sciences of Philadelphia, October 2, 1930.

A stated meeting of the Philadelphia Mineralogical Society was held on the above date, Mr. Toothaker presiding, with an attendance of sixty-seven. Upon favorable recommendation of the council, Mr. George Peterson was elected to membership. The following officers were elected to serve for the term 1930-1931:

President: Mr. Charles R. Toothaker.
 Vice-president: Mr. Morell Biernbaum.
 Secretary: Mr. Lester Strock.
 Treasurer: Mr. Wilfred Broadbelt.
 Councillor: Mr. Harry W. Trudell.

Mr. Toothaker described a trip taken with Messrs. Biernbaum, Clay, and Gordon in July to Virginia, North Carolina, and Georgia. At the Fanny Gouge mine near Burnsville, N.C., specimens of gummite, uraninite, cyrtolite, garnet, muscovite, pink zoisite, epidote, albite, and uranophane were collected on the dumps. At the McKinney mine near Crabtree creek specimens of muscovite, euxenite, columbite, and torbernite were collected. At least fifty square feet of quartz in the quarry was solidly covered with excellent crystallized torbernite. Epidote crystals were obtained at the Cullasagee Falls locality; and many amethysts were acquired at Hayesville and Franklin. Mr. Toothaker in an entertaining manner described the scenery in the mountainous sections of North Carolina, and gave details of the collecting experiences of the party. His remarks were illustrated with a series of colored slides, and many specimens.

Mr. Obert of Ridgewood, N.J., exhibited a fine series of prehnite and associated minerals from Paterson, N.J., a locality recently closed to visitors due to two accidental deaths (one a young collector). Mr. Knabe reported his activities in visiting some Pennsylvania localities.

LESTER W. STROCK, *Secretary*

NEW YORK MINERALOGICAL CLUB

The New York Mineralogical Club held its first meeting for the season of 1930-31 at the American Museum of Natural History, October 15, 1930. After approval of the minutes of the May meeting, Mrs. Marjorie F. Blank of Tuckahoe, N.Y., was elected to membership. The following were proposed as members: James A. Taylor,

Glen Ridge, N.J., Dr. R. B. Sosman and Mr. H. C. Lee, of Kearny, N.J.; William Casperson, of Paterson, N.J.; and E.J. Rouy, of Clifton, N.J., to be voted on after the report of the Membership Committee.

A report was made of the successful trip of the Club to the Bedford, New York quarries on Memorial Day. It was decided to hold a field day excursion at Paterson, N.J., on Election Day, Nov. 4. The Executive Committee was empowered to negotiate with Mr. Manchester regarding its measure of cooperation in the publication of his forthcoming book on the minerals of New York and vicinity. The secretary was instructed to send a message of sympathy to Ward's Natural Science Establishment for the loss sustained by the recent fire.

The program of the meeting consisted of exhibits by different members of minerals collected during the summer, with reports of their visits to various localities. Most important was the account by President Frederick I. Allen of his visit to Långban. He gave a graphic description of that famous locality, where iron and manganese ores of the normal types are associated with a great variety of rare minerals, and exhibited about fifteen specimens of the rarer species obtained by him on the spot. Others who reported and exhibited specimens from localities visited were Professor Hawkins of Rutgers University, and Messrs. Manchester, Hoadley, Radu, Weidhess and Morton. The season has opened auspiciously for the Club, and great activity is expected during the coming months.

JAMES F. MORTON, *Secretary*

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PREPARED BY L. S. RAMSDELL

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